Protocols for Asynchronous Communication in Space Operations: Communication Analysis

Completed Technology Project (2012 - 2016)

Project Introduction

Effective and efficient communication between Mission Control and space crews is essential for successful task performance and mission safety. The importance of team communication is heightened when unforeseen problems arise, such as system failures that are time-critical and require extensive coordination and collaboration between space and ground crews. During long duration missions and missions beyond Low Earth Orbit, space-ground communications will involve delays up to 20 minutes one-way, a reality that poses a formidable challenge to team communication and task performance. The overall aim of this research project was to develop and validate medium-specific communication protocols that enable flight controllers and space crews to establish and maintain common ground (i.e., mutual task and situation awareness) and coordinate problem solutions in response to different operational tasks during periods of communication delays. Specific project goals were: (1) Determine the impact of communication delays on communication, teamwork, and task performance in relation to varying task demands, i.e., procedural tasks vs. tasks requiring analysis and decision making, and different communication media (voice vs. text). (2) Develop and validate communication protocols to support joint problem solving and decision making by mission controllers and space crews during periods of asynchronous communication. To achieve these objectives several ground-based studies (space analog and laboratory) were conducted.

The first set of studies had the goal to determine how transmission delays of various lengths impact team communication and performance under different media conditions. Findings then informed the design of medium-specific communication protocols. Their feasibility for space missions was assessed in two analog environments s [Human Exploration Research Analog (HERA) and NASA Extreme Environment Mission Operations NEEMO)]. A complimentary laboratory study was conducted to examine further whether the availability of protocols enhanced remote team members' communication and task performance during periods of communication delay.

Anticipated Benefits

Our research resulted in the design of communication protocols and a training module that support collaborative problem solving and decision making by teams that are distributed across Earth and space and communicate asynchronously. Communication protocols could also be used to support collaborative work within on-ground distributed synchronous teams, for instance, during military operations or in telemedicine. Moreover, the communication protocols also point to technological solutions. One example is the text tool that was adopted in one space simulation and assisted the crew with the temporal aspects of communication. Further improvements might be a less chat- and more email-like text tool that includes a subject header and links between related messages to make it easier for conversational partners

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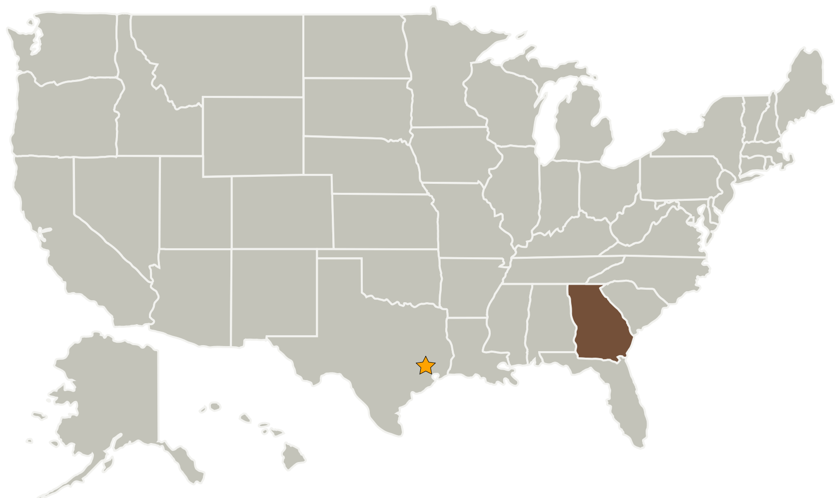
to follow a conversational thread. A text tool could also provide a template that gives structure to a message and highlights its components. Likewise, voice communication could be facilitated if recordings of messages were available to both sender and receiver. Moreover, the recording could indicate when a message was transmitted, and it is conceivable that the recording tool would include prompts for specific message components.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Johnson Space Center(JSC)	Lead Organization	NASA Center	Houston, Texas
Georgia Institute of Technology-Main Campus(GA Tech)	Supporting Organization	Academia	Atlanta, Georgia
San Francisco State University(SFSU)	Supporting Organization	Academia	San Francisco, California

Primary U.S. Work Locations
Georgia

Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Center / Facility:

Johnson Space Center (JSC)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

David K Baumann

Project Manager:

Lauren B Leveton

Principal Investigator:

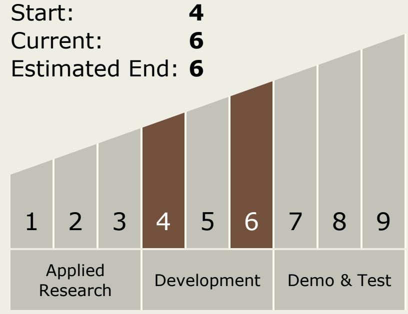
Ute Fischer

Co-Investigator:

Kathleen Mosier

Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **6**



Project Transitions

September 2012: Project Start

Technology Areas

Primary:

- TX07 Exploration Destination Systems
  - └─ TX07.3 Mission Operations and Safety
    - └─ TX07.3.2 Integrated Flight Operations Systems

Target Destinations

The Moon, Mars

August 2016: Closed out

Closeout Summary: Our first study consisted of an analysis of the communications between astronauts and Mission Contr ol personnel recorded as part of the Autonomous Mission Operation (AMO) study conducted by Frank, Spirkovska, McCann, et al. (2013). In a second, laboratory, study we examined the impact of communication delay in relation to different comm unication media. Findings from these studies informed the design of medium-specific communication protocols as they highl ighted which aspects of the communication process need support to ensure successful communication between remote part ners under asynchronous conditions. The effectiveness and feasibility of communication protocols for space operations was subsequently assessed in two studies, resulting in refinements of the protocols and the design of a communication training module. Analysis of the AMO data provided first insights into the effects of transmission delays on team communication. Sp ecifically, we observed that transmission delays disrupted the timing and structure of turns (i.e., communications by differe nt team members). Communications by different speakers co-occurred (i.e., step-ons in which team members talked over e ach other) or were out of sequence (i.e., related turns by partners did not follow each other as one partner inserted a turn before the addressee could respond to the initial contribution). Both types of disruptions likely increased team members' co gnitive workload and jeopardized common ground (i.e., mutual task and team awareness). Step-ons compromised mutual understanding insofar as parts of a message were inaudible and required additional turns to repair which, given the transmi ssion delay, were likely associated with considerable costs both in terms of time and workload (as partners had to wait for c ritical information and keep track of concurrent tasks). Contributions that were out of sequence could undermine mutual un derstanding in at least two important respects. When related contributions by members of the flight control team and the s pace crew did not immediately follow each other, partners had to keep track which conversation was still open requiring a r esponse. This increased cognitive demand on team members may account for the finding that they frequently failed to resp ond to a partner's communication. Contributions that were out of sequence could also come too late; that is, a communicati on was overtaken by events and thus reached the addressee after the fact. In a companion laboratory study we explored th e impact of transmission delay on team communication and task performance in relation to varying task demands (procedu ral vs. ill-defined), and different communication media (voice vs. text). Spatially distributed teams of three collaborated in a computer-based task environment and communicated either by voice-over-internet or via a texting tool. The micro-world fo r the study was AutoCAMS 2.0 (Manzey et al., 2008) which simulates the life support system of a spacecraft and requires te am members to monitor and control different subsystems, and to diagnose and repair failures. Each team was required to p erform procedural and problem solving tasks during one synchronous and one asynchronous flight segment (5-min one-way delay in communications transmission). Each flight segment lasted for 90 minutes. In order to guarantee the requirement o f communication and collaboration on the experimental tasks, task-related expertise concerning diagnostic and repair proce dures was differentially distributed among team members. The Flight System Engineer (FSE) received extensive training on AutoCAMS systems, diagnoses, and repairs, and had access to a comprehensive reference manual. The two Pioneer crewme mbers were given basic training on AutoCAMS and were instructed to contact the FSE for guidance on diagnosis and repair whenever a failure occurred on their system. Analyses of team performance revealed that transmission delay impacted time required to initiate a successful repair and more importantly, that its effect varied by communication medium. When comm unication was delayed, teams used a comparable amount of time to repair system failures, irrespective of the communicatio n medium used. However, when communication was synchronous, voice teams outperformed text groups. Likewise, teams' accuracy in performing system repairs was influenced by communication medium. Overall, teams communicating by text un dertook more incorrect repairs than teams communicating by voice. Analysis of FSE/Pioneer communications revealed that communication delay influenced both the rate of turns by team members and the length of their contributions. Team memb ers made fewer but longer contributions when they communicated under time delay than when no time delay was present. Moreover, these effects were more pronounced for teams communicating by voice than those communicating via text. This finding suggests that team members using text may have been more concise than team members in the voice condition. Ho wever, subsequent content analyses of Pioneer Crew/FSE interactions during transmission delay revealed that text commun ication was also associated with an increased potential for misunderstanding. Text teams were more likely than voice teams to split up related information and present it in separate turns. Related communications (adjacency pairs such as question a nd answer) by distributed team members were also further apart (i.e., more unrelated messages intervened) in text- than i n voice-based communications. Text communication also included more threats to common ground, in particular missing re sponses and anaphora (i.e., terms whose meaning could not be established within a turn but depended on information prov ided in preceding turns). These differences are consistent with medium-specific affordances and constraints. Text provides t eam members with a written record of their on-going conversation, and thus may enable them to keep track of related cont ributions and the identity of referents across turns. However, as the presence of communication problems in the text group indicates, team members may have overestimated the benefits of text-based communication. Voice communication is cogni

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Project Website:

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